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The Influence of Adjacent Seating Configurations on Egress Through a Type III Emergency Exit

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16. Abstract

When the United Kingdom Civil Aviation Authority (CAA) established a mandatory action intended to improve access to, and opening of, Type III emergency exits, the Northwest Mountain Region identified a need for a study to evaluate the proposed changes against existing minimum requirements of the Federal Aviation Regulations (FAR).

Four seating configurations were chosen for the study. One met the existing minimum CAA requirements, one met the minimum requirements of the CAA mandatory action, one met the minimum FAR requirements, and a fourth configuration was chosen as a possible effective alternative. The seating configurations and a Type III exit were installed in the Civil Aeromedical Institute (CAMI) Evacuation Test Facility. Four groups of paid subjects were evacuated from the facility using each of the seating configurations in a counterbalanced sequence. A second phase of the study looked at exit preparation time with the seating configurations and the exit installed in a cabin section mock-up.

The results indicate that the proposed CAA configuration and the alternative configuration were both more effective than the minimum configuration required by the FARs as measured by evacuation flow rate. There were no significant differences in the exit preparation time among the four seating arrangements.

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THE INFLUENCE OF ADJACENT SEATING CONFIGURATIONS ON EGRESS THROUGH A TYPE III EMERGENCY EXIT

INTRODUCTION

As a result of the British Airtours Boeing 737 accident at Manchester on August 22, 1985 (1), the United Kingdom Civil Aviation Authority (CAA) established a mandatory action (2) intended to improve access to, and opening of, Type III (overwing) emergency exits. To assess the potential impact of these changes, the Northwest Mountain Region of the Federal Aviation Administration (FAA) identified a need for a study to evaluate the proposed changes under conditions that would enable comparison with the minimum requirements of the Federal Aviation Regulations (FAR).

Initial discussions between the Northwest Mountain Region and the Civil Aeromedical Institute (CAMI) concerning such a study took place in April 1986. Authorization to conduct the study was received at CAMI in June 1986. Discussions with the Regulatory Branch of the Aircraft Certification Division (ANM-112), and informal contacts with the CAA, resulted in the selection of two representative and two alternative seating configurations for comparison. Subsequently, it was also decided to conduct the study in two phases. The first phase would compare exit flowrates and the second would compare exit preparation times.

METHODS

Subjects. The subjects were required to be free of physical impairments that would limit their ability to perform the task activities. They also had to have an adequate comprehension of the English language to understand the instructions and safety warnings that were an integral part of each trial. No subject had any professional experience with aircraft emergency evacuation or any direct participation in similar activities during the preceding three years.

The subjects in the exit flowrate phase of the study were 127 paid volunteers and four FAA employees ranging from 17 to 70 years of age. The FAA employees were included to fill vacancies that resulted when several contract subjects failed to report as scheduled. The FAA employees were assigned no special roles and met the same requirements as the other subjects.

The subjects reported in four groups on four separate days. Each group was roughly matched for age and sex distribution. No attempt was made to match the groups by any other characteristics. A summary description of each group is presented in Appendix A.

The 40 active subjects used in the exit preparation phase of the study were paid volunteers ranging from 19 to 58 years of age. They were divided into five roughly matched groups of eight subjects each by selection from the subject pool available on the scheduled test date. A summary description of each group of active subjects is presented in Appendix B. Data for passive subjects who occupied adjacent seats are not included.

Test Facility. The CAMI Evacuation Test Facility cabin was furnished with 14 rows of three-abreast seat assemblies installed with a 32 inch seat pitch on both sides of a 17 inch wide aisle. This arrangement was retained for the exit flowrate trials except for the changes required to provide the specified seating configurations adjacent to the Type III exit. When these changes resulted in a seatrow having less than a 32 inch seat pitch, that seatrow was not occupied during trials with that configuration.

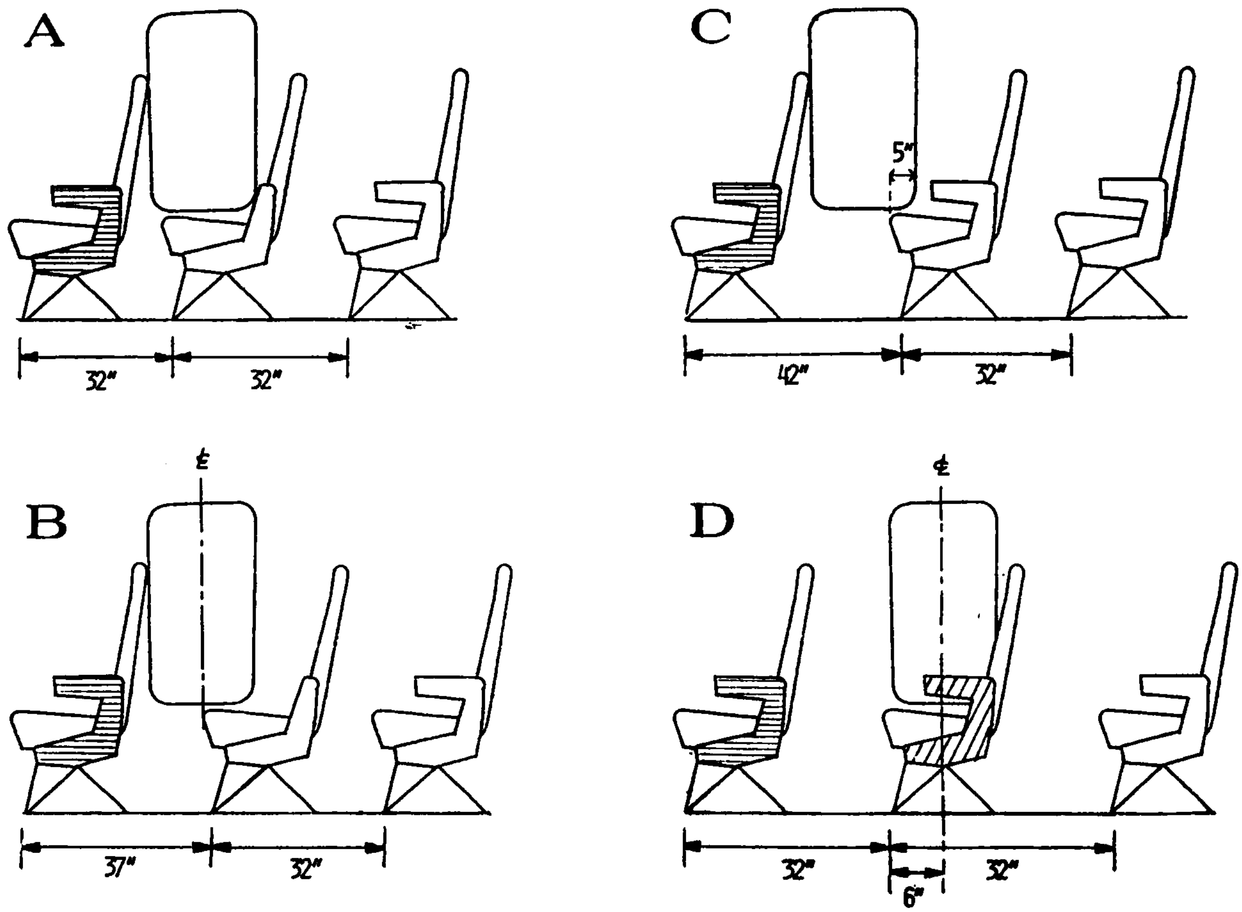
The four seating configurations used in both phases of the study are illustrated in Figure 1 and met the following specified requirements:

A. The FAA minimum standard for access currently allowed per FAR Section 25.807(a)(3) and 25.813(c)(1). This places the seat forward of the exit as far aft as possible without having any part of the seat encroach upon the exit and the aft seat as far forward as possible without the seat back encroaching into the exit opening.

B. The CAA minimum standard (2). This provides 10 inches between the seat forward (and clear) of the exit and the seat aft of the exit which has its leading edge no farther forward than the centerline of the exit.

C. A configuration in which the seat forward of the exit is completely clear of the exit and the leading edge of the seat aft of the exit encroaches no more than five inches into the exit opening. This provides a clear opening about 20 inches wide centered on the exit.

D. A configuration in which a seatrow is essentially centered in the exit, but has the outboard seat place removed. The seats fore and aft are at a normal seat pitch of approximately 32 inches, but do not encroach upon the exit.



Notes:

1. All values are in inches as installed in test facility. Seat pitch values varied less than an inch for comparable seat assemblies and configurations used during exit preparation phase.

2. Numbers on seats identify the following seat assemblies used during the exit preparation phase.

   - Fairchild FBC-2000-3
   - Fairchild FBC-2000-3-59 (modified)
   - Fairchild 41281037 REV

3. All seat assemblies used in the flow rate phase were JAL Type 8 Stock Nr. 958. (A modified assembly was used adjacent to the exit for configuration "D").

FIGURE 1. Schematic representation of the four evaluated seating configurations.

The Type III exit was salvaged from a crashed B-720 aircraft and restored to a functional (though not certifiable) condition. The exit assembly was installed in the fuselage frame just forward of the mid-point of the interior cabin. The removable door plug assembly weighed 36 pounds as installed. The relevant exit area dimensions are given in Figure 2.

An overhead panel was suspended above the exit and several adjacent seat rows to simulate the overhead restriction imposed by a B-727 passenger cabin configuration. See Figure 2 for dimensional data.

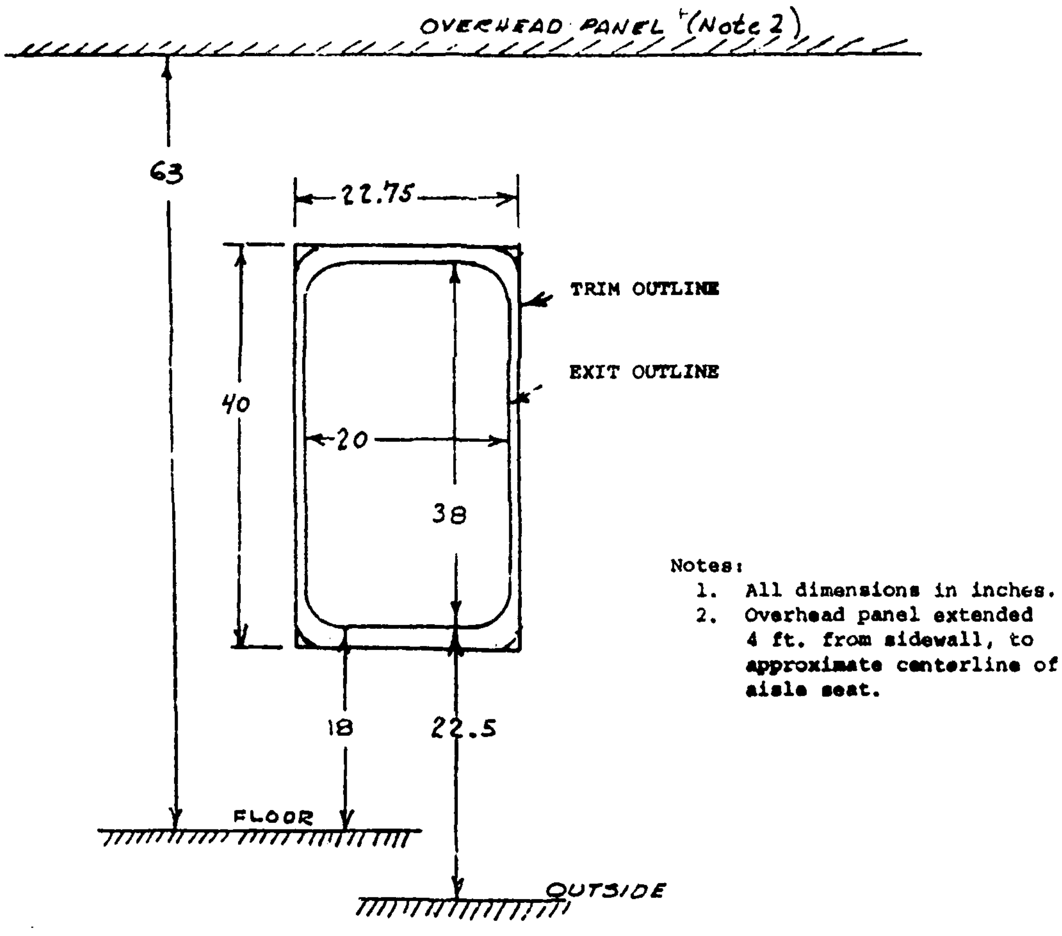


FIGURE 2. Exit installation for flowrate phase of study.

A mock-up of a right side cabin section, including a Type III exit, changeable seating configurations, and an overhead panel was constructed for the exit preparation phase of the study. The mock-up is illustrated in Figure 3. The exit specifications and the seating configurations were the same as those for the flowrate phase. A separate mock-up was deemed necessary because in preliminary tests, subjects frequently stowed the removed door in a space between the outboard seats and the sidewall of the evacuation test facility. Similar spaces do not normally occur in passenger aircraft cabins.

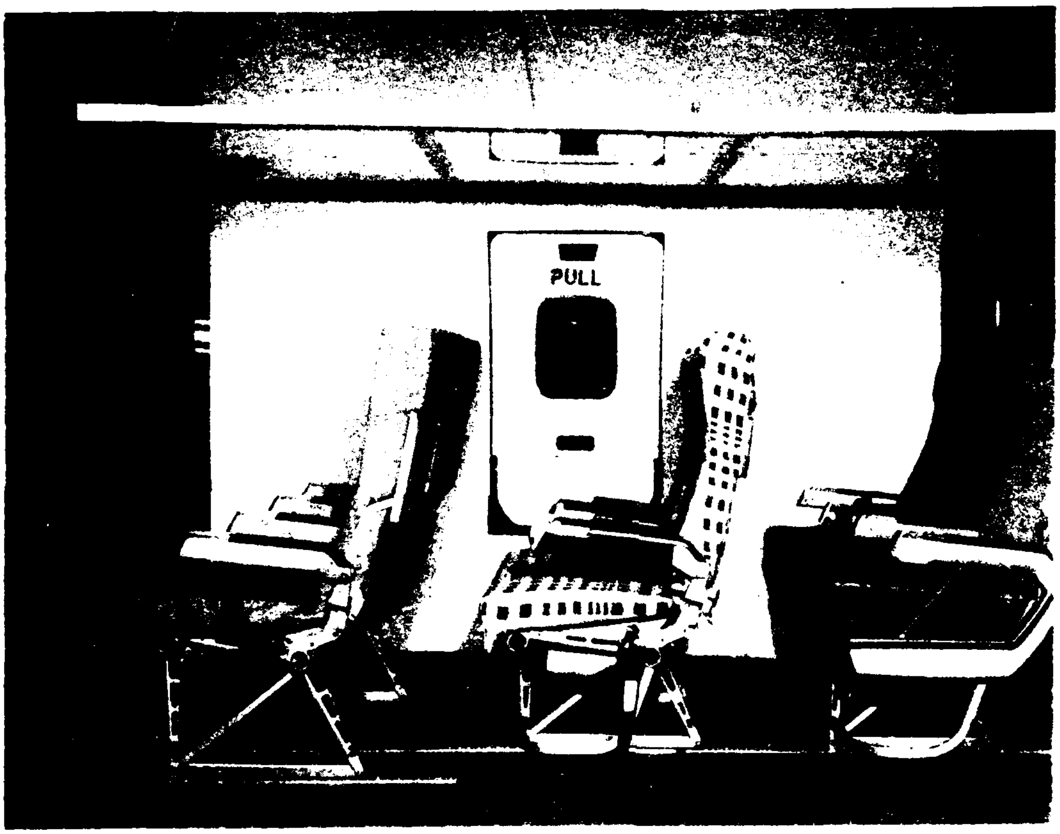


FIGURE 3. View of mock-up used in exit preparation trials.

Data Acquisition. Subject activity during exit flowrate trials was recorded by five separate video recording systems. Three cameras covered the interior exit area from different vantage points and two cameras covered the exterior. Three of the five systems were equipped to generate digital time signals superimposed on each video frame and served as the sources for timed performance data. Three systems were used to record subject activity during the exit preparation trials.

Other Equipment. An abbreviated "passenger information card" containing an illustration of the door removal procedure, supported by minimal language content, was provided for those subjects who were designated to prepare the exit. The card did not indicate how the door should be disposed of once removed from the exit frame. The contents of the card are shown in Figure 4.

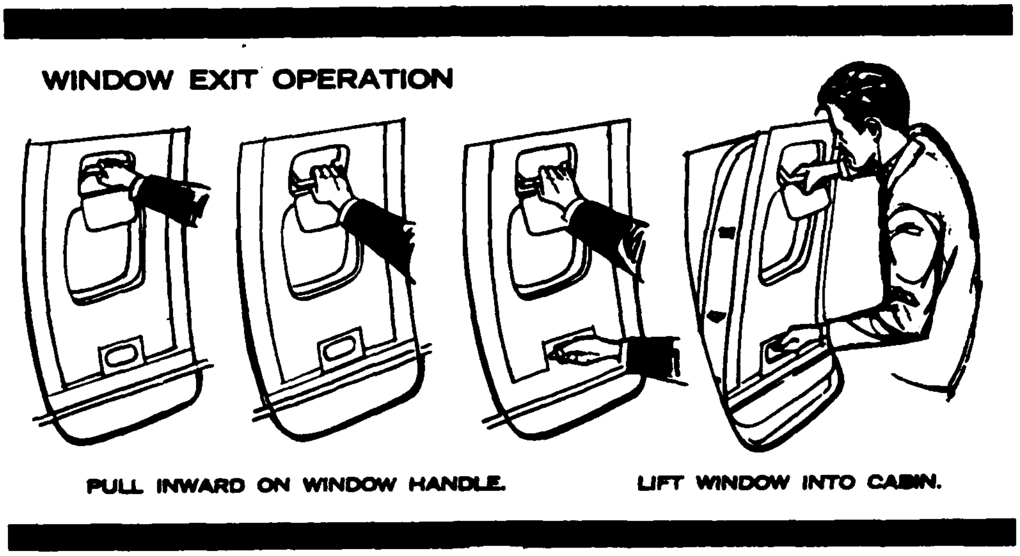


FIGURE 4. Content of abbreviated passenger information card used during both phases of study.

A loud bell was used to signal the start of the exit flowrate trials. A gently sloping ramp was positioned outside the exit to give the desired step-down distance. Guide ropes steered the exiting subjects away from stationary equipment positioned near the exit without creating a detectable impediment to movement away from the exit.

A loud buzzer was used to signal the start of the exit preparation trials. A signal light was positioned in each camera's view to indicate the onset of the starting signal for each trial. A second light, activated by the closure of a switch mounted at the exterior of the exit, indicated when the top of the door first started to move away from the exit frame.

PROCEDURE:

All subjects filled out a brief questionnaire asking for their sex, age, and handedness. They also read and signed an informed consent form outlining a general understanding of the study and of the rights and responsibilities of the subjects and the research team. Clothed weight to the nearest pound, and standing height with shoes to the nearest inch, were obtained by direct measurement. Each subject was issued a numbered vest to be worn over his/her outer clothing to identify individual subjects on the video record. A statement including the purpose of the project, an outline of what would be required of them, and the safety precautions to be observed was then read to the subjects as a group.

Exit Flowrate. For the exit flowrate trials the subjects were escorted to the evacuation test facility and directed to occupy any of the 36 designated seats fore and aft of the exit. When necessary, subjects were shifted so that all the seats in the immediate vicinity of the exit were occupied. A different male subject was selected at random and designated to open the exit for each trial and was seated accordingly. Prior to the beginning of the test the subjects were read a brief set of instructions covering the use of the seatbelt, how the start of the trial would be signaled, and which exit would be used. The need for maximum speed in exiting the facility, consistent with personal safety, was emphasized. No indications of advantageous procedures or techniques were given.

The subject designated to prepare the exit was provided with the information card just prior to the start of each trial and instructed to return it to the seat pocket when he had finished studying it. When all elements were determined to be ready, the experimenter signaled the start of the trial with an oscillatory bell which continued to sound throughout the trial. A loud and persistent urging to maximum speed was also voiced until the last subject exited the cabin. An observer recorded the vest numbers of the subjects as they emerged from the exit to facilitate analysis of the video records.

Upon completion of the trial the subjects were returned to a waiting area for approximately 20 minutes while the seating configuration was changed for the next trial. The procedure was repeated for each of the remaining trials. To minimize potential effects of fixed seat location, the subjects were asked to change their seat positions during successive trials by switching to the opposite side of the aisle, or moving fore or aft from their previous position. Subject seating locations were recorded for all trials but were not systematically controlled.

The four groups of subjects were presented the four seating configurations described in the methods section in counterbalanced sequences based on a Latin square design as follows:

SEQUENCE

	1st	2nd	3rd	4th
First Day:	A	B	C	D
Second Day:	D	C	B	A
Third Day:	C	A	D	B
Fourth Day:	B	D	A	C

Exit Preparation. For the exit preparation phase of the study, all trials with the same seating configuration were conducted in succession on the same day. The subject designated to prepare the exit was seated next to it, except during the replication of the trials with the outboard seat removed where the active subject was seated in the outboard seat of the seatrow aft of the exit. All seats in the middle row, and the aisle seats in the rows fore and aft, were occupied by passive subjects at the start of each trial. During the trials with the outboard seat removed, the middle, rather than the aisle seat of the aft seatrow, was occupied by a passive subject.

Prior to the beginning of each trial, the subjects were read a brief set of instructions covering how the start and conclusion of the trial would be signaled and the location of the exit to be used, and emphasizing maximum speed consistent with personal safety. No indications of advantageous procedures or techniques were given. The subject designated to prepare the exit was provided with an abbreviated passenger information card identical to the one used in the exit flowrate trials.

A buzzer was sounded for three seconds to signal the beginning of the trial. The trial was concluded by voice command when the experimenter deemed that the exit was available for use. After each trial, the active subject was dismissed and the one or two passive subjects in the middle seatrow were rotated to the fore and aft aisle seats, or other non-critical seat positions, from which previous occupants had also been dismissed. None of the active subjects, unlike some passive subjects, had any previous exposure to the experimental setting. Most passive subjects were used twice, and occasionally three times, when there were not enough subjects available to permit a complete replacement. Passive subjects are defined as those having no assigned responsibility for preparing the exit for use. A few of them did handle the door when they helped to move it away from the exit opening.

However, by that time, the exit was generally available for egress and the trial concluded for purposes of recording data. All seats for each trial were "mapped" with the vest number of the subject occupying the seat or were marked "vacant" as appropriate.

Data Reduction. All time values were taken from the running time markers on the video tapes and tabulated to the nearest tenth of a second. For the exit flowrate data, each subject's individual time is defined as the time it took for the subject to completely clear the external frame of the exit after the previous subject had cleared the exit frame. The time for the first subject in each trial was defined as the time it took to clear the exit after the opened exit was first available for egress. Exit preparation time was not included in the exit flowrate data.

Exit preparation times were tabulated as two separate task components, as well as the sum of the two. The first component was the break time, the time lapsing between the onset of the trial's starting buzzer and the instant when the top of the door first broke away from its seated position in the exit frame. This event was signaled by a light triggered by a switch mounted on the exit frame. This time includes the subject's response time and the initial disengaging of the door's retaining mechanism. The second component is the time it took from the moment the upper part of the door started to move away from the seated position until the door had been disposed of and the exit was deemed accessible for egress.

All time values were tabulated by the experimenters working independently. Discrepancies in the separately-tabulated values were resolved by joint assessment of the video record.

RESULTS

The mean times per subject to exit through the Type III exit with four different adjacent seating configurations are shown in Table 1 and plotted in Figure 5.

When data for all trials with the same seating configuration are combined, one-way analysis of variance shows significant differences among the four configurations (ANOVA $F = 4.74$, df 3, 520 $p < .01$). Independent 't' tests show significant differences between the means for the A and C configurations ('t' = 2.31, df 260, $p < .025$), the A and D configurations ('t' = 3.35, df 260, $p < .005$), and the B and D configurations ('t' = 2.39, df 260, $p < .01$).

TABLE 1. Mean of individual subject evacuation times (in seconds) and flow rate (subjects per minute) through a Type III emergency exit with four different adjacent seating configuration.

		CONFIGURATION			
		(A) FAA Std. Minimum	(B) CAA Std. Minimum	(C) 20" Min. w/5" Incr.	(D) OB Seat Removed
	Sequence:	(A)BCD	(B)DAC	(C)ADB	(D)CBA
FIRST TRIALS	Mean:	1.65	1.75	1.67	1.46
	SD:	.56	.56	.71	.41
	Rate:	36.4	34.3	35.9	41.1
	Sequence:	C(A)DB	A(B)CD	D(C)BA	B(D)AC
SECOND TRIALS	Mean:	1.81	1.41	1.50	1.38
	SD:	1.03	.39	.45	.32
	Rate:	33.2	42.5	40.0	43.5
	Sequence:	BD(A)C	DC(B)A	AB(C)D	CA(D)B
THIRD TRIALS	Mean:	1.49	1.47	1.29	1.37
	SD:	.48	.48	.33	.63
	Rate:	40.3	40.8	46.5	43.8
	Sequence:	DCB(A)	CAD(B)	BDA(C)	ABC(D)
FOURTH TRIALS	Mean:	1.53	1.44	1.31	1.28
	SD:	.64	.56	.36	.37
	Rate:	39.2	41.7	45.8	46.9
COMBINED TRIALS	Mean:	1.62	1.52	1.44	1.37
	SD:	.71	.51	.50	.45
	Rate:	37.0	39.5	41.7	43.8

One-way analysis of variance shows no statistically significant difference among the four configurations when applied only to the data for the first trials in each sequence (ANOVA F = 1.56, df 3,27). Independent 't' tests, however, show that the difference of the first trial means for the B and D configurations is statistically significant ('t'= 2.42, df 64, p.<.01). The differences of the means for all other paired comparisons were not significant at p.<.05 level of confidence.

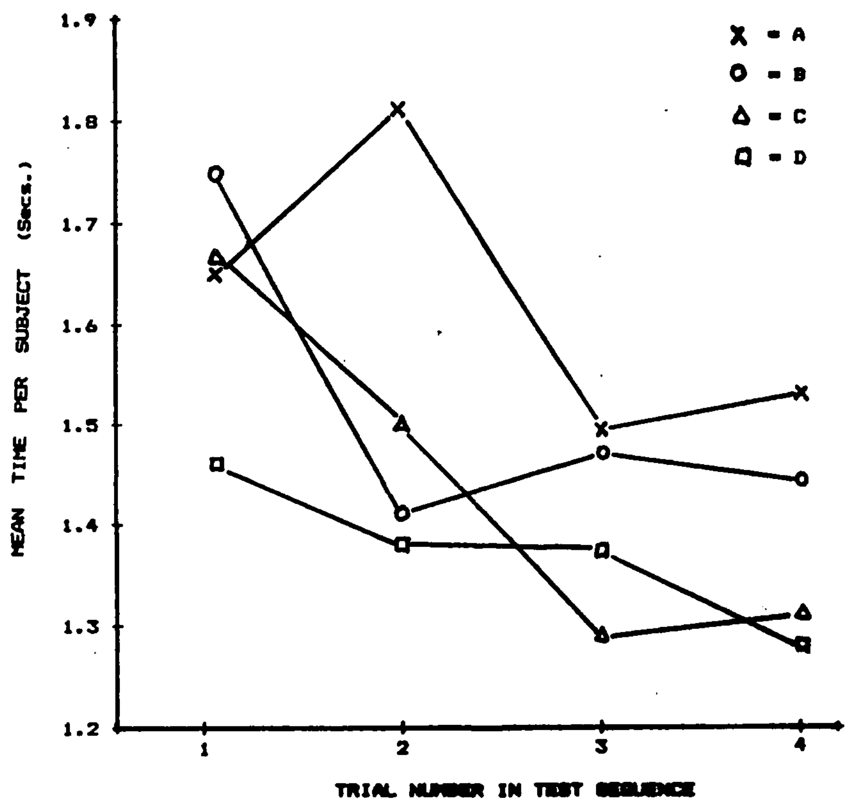


FIGURE 5. Means of individual subject evacuation times (in seconds) for four trials with each of four adjacent seating configurations.

Figure 6 shows the cumulative number of subjects exited at five second intervals for the first trials with each of the four seating configurations.

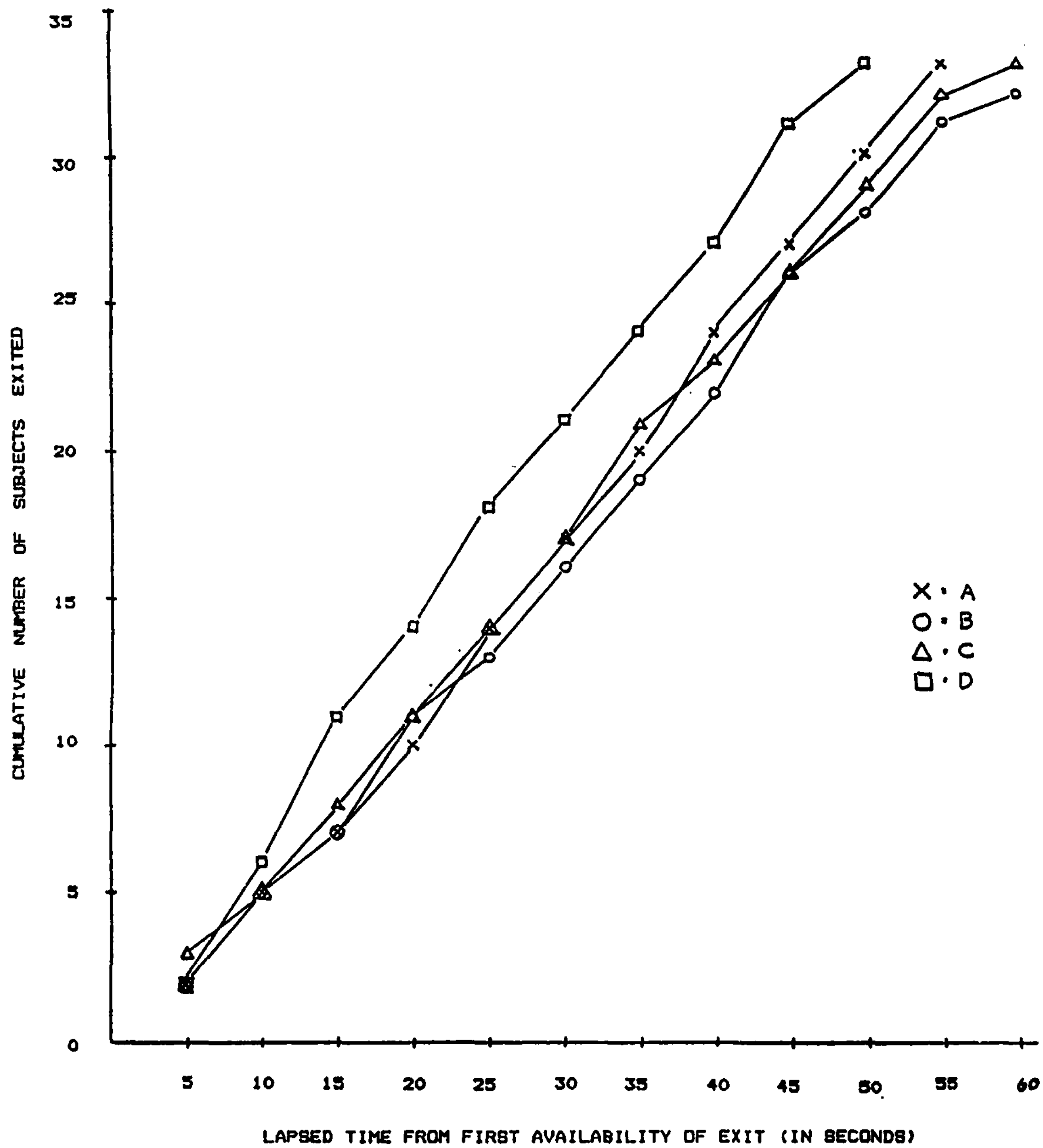


FIGURE 6. Cumulative number of subjects exited over time on first trials with each seating configuration.

The mean times to release the door retention latch and the mean times to prepare the exit are given in Table 2. One way analyses of variance failed to yield significant differences among the five conditions for any of the three measures. Independent 't' tests show that the only significant differences between the means are those for the latch release time for configurations A and C ('t' = 2.43, df 14, p.<.025), configurations A and D1 ('t' = 2.82, df 14, p.<.01), and configurations B and D1 ('t' = 1.80, df 14, p.<.05).

TABLE 2. Mean times (in seconds) to prepare a Type III emergency exit for egress with four different proximal seating configurations.

		CONFIGURATION				
		(A) FAA Std Minimum	(B) CAA Std Minimum	(C) 20" Min. w/5" En-croach.	(D1) OB Seat Removed (Adj.S.)	(D2) OB Seat Removed (Aft S.)
Time to Unlatch Door	Mean:	1.78	2.08	2.28	2.54	2.39
	SD:	.47	.41	.34	.60	1.36
Time to Dispose of Door	Mean:	3.79	3.55	3.33	3.68	2.61
	SD:	1.58	1.75	1.78	1.36	1.42
Total Prep. Time	Mean:	5.56	5.63	5.60	6.21	5.00
	SD:	1.95	1.93	1.74	1.79	2.33

(**Note**: Configurations D1 and D2 are identical. The operational distinction between the two is that for D1 the active subject was seated abreast of the exit and for D2 the active subject was seated in the outboard seat of the seatrow aft of the exit.)

DISCUSSION

Under the conditions of this study there are significant differences among the four seating configurations installed adjacent to a Type III emergency exit as measured by individual egress times. When limiting consideration to first trials, configuration D yielded the fastest individual mean egress time of the four configurations tested. However, only the difference between the mean for configuration B (1.75 sec.

per S.) and configuration D (1.46 sec. per S.) was shown to be significant at or beyond the .05 level of confidence by independent 't' test. The difference between configuration A (1.65 sec. per S.) and the faster configuration D (1.46 sec. per S.) was in the expected direction, but is significant only at the .10 level of confidence.

The differences between the four configurations as measured by egress rate, are much more pronounced when all data for the same configurations are combined. With the combined data there are not only differences between configurations A and D, and B and D, but also between A and C.

The inclusion of data from trials with subjects who had some immediate previous experience with a Type III exit, acted to minimize performance variability, a phenomenon generally associated with task training, and a major determiner of the statistical significance of the observed results. The marked effect of individual variability is demonstrated by the results for configuration A when it was second in the sequence. If the individual time for the subject with the largest value was to be dropped from the data the mean time for that trial would drop from 1.81 sec. to 1.67 sec.

One uncontrolled variable in the study was the effect of the location and general placement of the removed door plug assembly on egress rate. Although this phase of the study did not include egress data, it appears that an indiscriminately discarded door may well be more detrimental to safe and rapid egress than many other controllable factors. The magnitude of the adverse effect may also be directly related to the installed seating configuration. A door placed on the floor leaning against the forward seatback in a seat row with a 20 inch clearance will probably not impair rapid movement as much as when similarly positioned in the active seatrow with an existing minimum configuration.

The seating configurations themselves appear to influence how the door is disposed of, at least in the absence of specific instructions. When the configuration with the outboard seat removed was installed, the door was frequently positioned vertically on the floor leaning either against the sidewall next to the exit or against the forward outboard seatback. These placements were not judged to offer potentially significant obstructions to rapid egress. With the minimum FAA and CAA configurations, there were more instances of the door being placed vertically in the seat previously occupied by the person opening the exit or on the floor of the seatrow leading to the exit. Both of these placements can adversely affect the egress rate but the floor placement will generally be the most detrimental. This placement may require

those attempting to use the exit to step up into the seat to get past the door and/or move through the exit from a standing position on the outboard seat.

Additional tests would have to be conducted to quantify the specific effects of various door disposal locations and the interaction with existing or proposed seating configuration.

At the time of writing of this report, the results of this study had become part of the basis for a draft Notice of Proposed Rule Making (NPRM) currently being considered for publication in the Federal Register.

REFERENCES

1. AIB Bulletin (Special) S 3/85. Accident Investigation Branch, Department of Transportation, Royal Aircraft Establishment. Undated.

2. Airworthiness Notice No. 79. Access to and Opening of Type III Emergency Exits. Civil Aviation Authority, Issue 1, 22 November 1985.

APPENDIX A

Description of Subject Population for Flowrate Study

	SUBJECT GROUPS			
Subjects	A B C D	D C B A	C A D B	B D A C
Total Number	33	33	33	32
(male)	18	18	17	14
(female)	15	15	16	18
Mean Age	41.55	37.76	39.48	39.28
Std. Dev.	16.27	13.99	14.94	12.39
Age Range	21 - 70	18 - 65	18 - 68	17 - 65
Mean Height	69.00	68.30	68.21	68.34
Std. Dev.	3.68	3.70	2.64	4.20
Height Range	60 - 75	61 - 75	64 - 74	61 - 76
Mean Weight	175.76	167.67	152.82	165.22
Std. Dev.	41.98	39.95	23.77	31.60
Weight Range	112 - 281	95 - 275	106 - 201	112 - 248

Age in years (as of last birthdate).

Height in inches (measured to nearest full inch with shoes).

Weight in pounds (weighed to nearest full pound with shoes and clothing).

APPENDIX B

Description of Subject Population for Door Opening Study

Subjects	SUBJECT GROUPS				
	FAA Std Minimum	CAA Std Minimum	20" Min. w/5" Encroach.	OB Seat Removed (Adj.S.)	OB Seat Removed (Aft S.)
Total Number	8	8	8	8	8
(male)	4	5	4	4	4
(female)	4	3	4	4	4
Mean Age	38.25	30.63	37.75	33.75	33.13
Std. Dev.	9.85	6.63	14.74	11.06	10.36
Age Range	26 - 55	21 - 41	19 - 57	22 - 58	22 - 55
Mean Height	68.25	67.13	68.38	68.25	68.25
Std. Dev.	2.76	4.85	4.60	5.68	3.49
Height Range	65 - 72	61 - 75	60 - 72	58 - 77	64 - 73
Mean Weight	164.63	161.38	160.00	154.25	150.25
Std. Dev.	66.25	35.67	35.54	41.16	23.14
Weight Range	119-235	119-226	114-228	101-245	127-196

Ages in years (as of last birthdate).

Height in inches (measured to nearest full inch with shoes).

Weight in pounds (weighed to nearest full pound with shoes and clothing).

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